CULTIVAR

Registration of 'Sidney' Spring Feed Barley Resistant to Russian Wheat Aphid

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ABSTRACT

'Sidney' (Reg. No. CV-344, PI 641939), a Russian wheat aphid [RWA, *Diuraphis noxia* (Kurdjumov)]–resistant, spring, two-rowed, feed barley (*Hordeum vulgare* L.) tested as 98BX 44B, was developed and released by the USDA–ARS, Stillwater, OK, and Aberdeen, ID; Colorado State University; and the University of Nebraska. Introduction of RWA to the United States effectively eliminated spring barley, the preferred alternate crop, in winter wheat (*Triticum aestivum* L.) rotations, in eastern Colorado and western Nebraska. 'Otis', a spring barley well adapted to the high dry plains, is susceptible to RWA. STARS 9301B, the first RWA-resistant barley germplasm line released in the United States, has a high level of resistance to the aphid. With RWA resistance from STARS 9301B transferred to Otis through backcross breeding, Sidney outperforms Otis in this marginal production area.

'Sidney' (Reg. No. CV-344, PI 641939) a Russian wheat aphid [RWA, *Diuraphis noxia* (Kurdjumov)]–resistant, spring, two-rowed, feed barley (*Hordeum vulgare* L.) tested as 98BX 44B, was developed and jointly released by the USDA–ARS, Stillwater, OK; USDA–ARS, Aberdeen, ID; Colorado State University; and the University of Nebraska. Since 1986, RWA has been a persistent pest of small grains in eastern Colorado, western Nebraska and Kansas, and southeastern Wyoming. The hot dry plains in these areas are marginal small grains dryland production areas where crop rotations are necessary for moisture conservation as well as reduction of soil erosion. Until the introduction of the RWA in 1986, feed barley was successful as the alternate crop in winter wheat (*Triticum aestivum* L.) rotations and valued as an irrigated feed crop. All barley cultivars that were available in the 1980s are susceptible to RWA. Russian wheat aphid prevents newly emerging leaves from unrolling, resulting in head entrapment and yield loss, and protecting the aphids from contact insecticides. Under heavy infestations, effective control requires multiple applications of systemic insecticides which are environmentally undesirable and economically prohibitive in these marginal dryland production areas. For the growing seasons of 1984 to 1986, an average of 62,700 ha of barley was planted in 16 eastern Colorado counties with gross sales of $14 million. In 2004, only 280 ha were planted and the average gross sales from the same counties from 1994 to 2004 was only $750,000 annually (Bosley, 2006). Our breeding objective was to develop a RWA-resistant feed barley suited to production in eastern Colorado, western Nebraska and Kansas, and southeastern Wyoming.

Sidney has the pedigree 'Otis'*4/STARS 9301B. Otis (PI 8775) was selected from the cross 'Munsing' (CI 6009)/'Spartan' (CI 5027). Otis was developed specifically for the high dry plains and released by Colorado State University in 1951 (Robertson, 1965) as an early-maturing, spring feed barley with high test weight and excellent yields under dryland conditions. The preferred alternate crop in winter wheat rotations for many years in Colorado, Otis is highly susceptible to RWA. STARS 9301B (PI 573080) was the first RWA-resistant spring barley germplasm line developed in the United States (Mornhinweg et al., 1995b). STARS 9301B is a highly RWA resistant selection from PI 366450, an accession collected in Afghanistan.

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Abbreviations: QTL, quantitative trait locus; RWA, Russian wheat aphid.

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Methods

Sidney was developed via a modified backcross breeding procedure in which each BC_xF_1 progeny population was screened for RWA resistance. Successive backcrosses were made with resistant BC_xF_1 plants. Resistance screening was conducted as described by Webster et al. (1991) and BC_xF_1 plants were selected with resistance ratings of 2 on Webster's scale of 1 to 9 where a rating of 1 to 3 is resistant, 4 to 6 is moderately resistant to moderately susceptible, and 7 to 9 is susceptible (Webster et al., 1991). BC_3F_1 were increased to BC_3F_2 and screened in the greenhouse for RWA resistance. Approximately 130 resistant BC_3F_2 were increased in the greenhouse and resultant $BC_3F_{2:3}$ planted as plant rows in the field in Aberdeen, ID, in spring 2000 for agronomic evaluation and Breeder seed increase. Remnant seed from each $BC_3F_{2:3}$ was screened in the greenhouse as above and homozygous resistant lines were identified.

Selected resistant lines, Otis, and Otis treated with Gaucho (Otis + Gaucho) insecticidal seed treatment (Imidacloprid, Bayer Agricultural Products, Kansas City, MO), which controls early-season RWA infestations, were evaluated in replicated yield trials in 2001 through 2004 at 12 location-years in eastern Colorado and western Nebraska (Table 1). Plot size was 152 by 914 cm with 30.5-cm row spacing and a seeding rate of 70 kg ha^{-1}. The RWA-resistant cultivar Burton (Bregitzer et al., 2005) and RWA-susceptible cultivar Baronesse (developed by Nordsaat in Germany and marketed in the United States by Westbred, LLC, Bozeman, MT) were also tested at one location in 2002 and four locations in 2004. These are truly dryland areas where 30-yr (1971–2000) average annual rainfalls are 40.23 cm (15.84 inches) in eastern Colorado and 40.00 cm (15.75 inches) in western Nebraska (High Plains Climate Center, http://www.hprcc.unl.edu/data/historical/ [verified 17 July 2009]). An extreme range of environments were encountered in this 4-yr testing period (Table 1). Rainfall ranged from 22.8 cm (9 inches) to 5.08 cm (2 inches) in January through June where annual average precipitation for those months is 20.3 to 22.86 cm (8–9 inches). Days from May through June with temperatures over 32°C (90°F) ranged from 1 to 21. Three locations were hailed out and one location-year was so dry the crop did not establish. Some locations were artificially infested with RWA by laying infested leaves in the plots. Other locations were either naturally infested (very lightly so) or aphid free (Table 1). Data collected included heading date (date of head emergence from the boot for 50% of plants), plant height, grain yield, test weight, percentage plump kernels (defined as the percentage of kernels retained on a sieve with 19.1- by 2.38-mm rectangular openings, Method Barley 2C: Assortment test; American Society of Brewing Chemists 1992), and aphid number per 20 tillers. Data were analyzed by a general analysis of variance via Statistix 9 (Analytical Software, Tallahassee, FL) and pairwise mean comparisons made using Tukey's HSD with $p < 0.05$. Data from locations with light natural infestations were pooled with data with no infestation in analyses because the light infestations were considered to have negligible affects.

Sidney was observed to be uniform from the BC_3F_3 through BC_3F_7 generation. Three hundred BC_3F_7 heads were selected from 2004 yield trials at Ft. Collins, CO, and screened in the greenhouse for RWA resistance. Seedlings from all heads had RWA resistance ratings of 2. Remnant seed from selected heads were bulked for Breeder seed and deposited into the USDA–ARS National Center for Genetic Resources Preservation in Ft. Collins. Seed from the 2004 plots in Ft. Collins was also utilized as Breeder seed for increase by Agronomy Foundation Seed, Soil and Crop Sciences, Colorado State University.

Table 1. Growing conditions and number of replications for each location and year.

Location	Year	Replications	RWA†	Temp.‡	Rainfall‡
				°C	cm
Stoneham, CO	2001	4	NI	–1.1	–4.70
	2002	4	NI	0	–16.92
	2004	3	NI	0	–6.68
Ft. Collins, CO	2002	2	AI	0	–11.73
	2002	2	AI	0	–14.27
	2003	4	AI	–	–9.91
	2004	4	NI	0	–11.86
Akron, CO	2003	4	NI	–2.2	–0.89
	2004	4	NI	–0.6	–7.16
Sidney, NE	2002	4	NI	+0.6	–13.77
	2003	4	AI	–1.1	+0.61

†RWA, Russian wheat aphid; NI, no or light natural infestation; AI, artificially infested with RWA.

‡Average maximum temperature February through June, average rainfall January through June compared to a 30-yr average (1971–2000) for the nearest recording station; High Plains Regional Climate Center (http://www.hprcc.unl.edu/data/historical/ [verified 17 July 2009]).

Characteristics

Sidney is a hulled, RWA-resistant, spring, two-rowed, feed barley with lax, midlong to long spikes that nod slightly at maturity. Spikes do not always emerge from the boot under severe drought conditions. Lateral glumes are reduced, and rachis edges have many long hairs. Lemma awns are long and smooth, while glume awns are rough and equal to the length of the glume. Glumes are covered with long hairs. Rachilla hairs are long, and the crease is V-shaped. Hulls are semiwrinkled with moderately predominate lateral veins. Lateral veins have few teeth, while marginal veins have none. Kernels are medium in size, plump, and symmetrical with a depression that tends to crease at the base. The aleurone is white. Sidney has the same maturity as Otis.

Sidney has a RWA resistance rating of 2 on Webster's scale of 1 to 9 (Webster et al., 1991). Russian wheat aphid resistance in donor parent STARS 9301B was determined to be controlled by one incompletely dominant gene, *Rdn1*, and one dominant gene, *Rdn2*, with recessive epistasis of *Rdn2* on *Rdn1* (Mornhinweg et al., 1995a). This source of resistance has been shown to provide significant protection against loss of agronomic performance (Mornhinweg

et al., 2006; Bregitzer et al., 2003). Two major quantitative trait loci (QTLs) for RWA resistance in STARS 9301B have been mapped to chromosomes 1H and 3H with one minor QTL on 2H (Mittal et al., 2008). The QTL on 1H showed dominance and is likely *Rdn2* while the QTL on 3H showed additive effects and is likely *Rdn1*. There was no evidence of epistasis in the QTL analysis, and it was suggested that the third QTL could be responsible for the original hypothesis of epistasis among *Rdn1* and *Rdn2*. The comparable level of resistance in Sidney and STARS 9301B suggests all QTLs are present in Sidney. The major component of resistance in STARS 9301B is tolerance with antibiosis as a secondary mechanism (Webster et al., 1991). Leaves of Sidney do not roll or streak under RWA infestation. Although selected for resistance to RWA1, STARS 9301B has been reported to be resistant to five (RWA1-RWA5) of the eight RWA biotypes reported on wheat (Puterka et al., 2006). Sidney, with resistance from STARS 9301B, has been reported to have resistance to RWA6-RWA8 (Weiland et al., 2008).

Analysis of variance over all location-years for Sidney, Otis, and Otis + Gaucho indicated a significant location effect for all traits and a significant cultivar and cultivar × location effect for all traits except RWA number (Table 2). Cultivar × location interaction was not significant for any trait, including aphid number, when analysis included only the four infested location-years and not significant for plant height and grain yield when only the seven no or naturally light infested location-years were analyzed.

No significant difference was found in the means of Sidney, Otis + Gaucho, and Otis for plant height (Table 3) at artificially infested location-years. Sidney had significantly greater grain yield than Otis both when artificially infested and under no or a natural light infestation of RWA. Grain yield of Sidney was not significantly different from that of Otis + Gaucho. Sidney had significantly greater test weight than Otis and significantly greater percentage of plump kernels than Otis and Otis + Gaucho under artificial RWA infestation. Otis had nearly threefold more RWAs per 20 tillers than Sidney and Otis + Gaucho. Besides the antibiosis component of Sidney's resistance, leaves of tolerant Sidney are flat and RWA are not protected from wind and rain as they are in the rolled leaves of susceptible parent Otis. Sidney was significantly taller than Otis and Otis + Gaucho when there was no RWA or a natural light infestation. Test weight of Sidney was not significantly different from Otis or Otis + Gaucho at six of seven locations with no or light natural infestation (Table 4). However, Sidney had a significantly greater percentage of plump kernels than Otis at all location-years and Otis + Gaucho in Akron, CO.

Burton, the first RWA-resistant feed barley (Bregitzer et al., 2005), also has resistance from STARS 9301B, in a mixed background of Baronesse, 'Crystal', and 'Klages'. Burton and Baronesse, a dryland feed barley susceptible to RWA, were tested along with Sidney at the four location-years with no or light natural infestations (Table 5). Sidney did not differ significantly from Burton for any trait except grain yield. Sidney had grain yields significantly greater than Burton at two locations and equal to Burton at two

Table 2. Analysis of variance for agronomic traits and aphid number over different location-years.

	Height	Grain yield	Test weight	Plump kernels†	RWAs per 20 tillers‡
	cm	kg hL^{-1}	kg m^{-3}	%	
All location-years					
Location	<0.001	<0.001	<0.001	<0.001	0.005
Cultivar	<0.001	<0.001	<0.001	<0.001	ns§
Cultivar × location	<0.001	0.002	0.015	0.008	ns
7 location-years, with RWA					
Cultivar × location	ns	ns	ns	ns	ns
4 location-years, no RWA					
Cultivar × location	ns	ns	0.015	0.002	

†Defined as percentage of kernels retained on a sieve with 19.1- by 2.38-mm rectangular openings, Method Barley 2C: Assortment test (American Society of Brewing Chemists, 1992).

‡Four infested location-years only, RWA, Russian wheat aphid.

§ns, not significant.

Table 3. Agronomic performance of barley 'Sidney', 'Otis', and Otis + Gaucho insecticidal seed treatment.

Cultivars	Location-years	Height	Grain yield	Test weight	Plump kernels†‡	RWA per 20 tillers§
	no.	cm	kg ha^{-1}	kg m^{-3}	%	
Artificially infested	4					
Sidney		64	1920a¶	603a	74a	163b
Otis + Gaucho		60	2067a	591a	61b	184b
Otis		55	1169b	549b	59b	506a
No or light infested	7					
Sidney		57a	1543a			
Otis + Gaucho		52b	1472ab			
Otis		53b	1354b			

†Defined as percentage of kernels retained on a sieve with 19.1- by 2.38-mm rectangular openings, Method Barley 2C: Assortment test (American Society of Brewing Chemists, 1992).

‡2 location-years only.

§RWA. Russian wheat aphid.

¶Means in a column with the same letters are not significantly different from each other according to Tukey's HSD, $\alpha = 0.05$.

Table 4. Kernel quality of barley 'Sidney', 'Otis' + Gaucho insecticidal seed treatment, and Otis measured at seven locations with no Russian wheat aphid or a natural light infestation.

	Test weight	Plump kernels†
	kg m^{-3}	%
Sidney, NE 2002		
Sidney	498	
Otis + Gaucho	521	
Otis	520	
Akron, CO 2003		
Sidney	586	73a‡
Otis + Gaucho	582	65b
Otis	586	64b
Akron, CO 2004		
Sidney	612	88a
Otis + Gaucho	595	71b
Otis	589	59b
Stoneham, CO 2001		
Sidney	537	
Otis + Gaucho	564	
Otis	570	
Stoneham, CO 2002		
Sidney	534	
Otis + Gaucho	545	
Otis	530	
Stoneham, CO 2004		
Sidney	577	42a
Otis + Gaucho	558	13ab
Otis	494	9b
Ft. Collins, CO 2004		
Sidney	630b	97a
Otis + Gaucho	656a	96ab
Otis	630b	92b

†Defined as percentage of kernels retained on a sieve with 19.1- by 2.38-mm rectangular openings, Method Barley 2C: Assortment test (American Society of Brewing Chemists, 1992).

‡Means in a column with the same letters are not significantly different from each other according to Tukey's HSD, $\alpha = 0.05$.

Table 5. Agronomic performance of 'Sidney', 'Burton', and 'Baronesse' barley at four locations with no Russian wheat aphid or a natural light infestation.

Cultivar	Height	Grain yield	Test weight	Plump kernels†
	cm	kg ha^{-1}	kg m^{-3}	%
Sidney, NE 2002				
Sidney		304a‡		
Burton		24b		
Baronesse		17b		
Akron, CO 2004				
Sidney	61a	2171a	312	88a
Burton	53ab	1563b	305	79ab
Baronesse	49b	1487b	300	70b
Ft. Collins, CO 2004				
Sidney	58a	2064a	630a	96a
Burton	55ab	2313a	632a	89ab
Baronesse	46b	1438a	611b	77b
Stoneham, CO 2004				
Sidney	42	406ab	576	42a
Burton	44	717a	537	21ab
Baronesse	36	222b	494	11b

†Defined as percentage of kernels retained on a sieve with 19.1- by 2.38-mm rectangular openings, Method Barley 2C: Assortment test (American Society of Brewing Chemists, 1992).

‡Means in a column with the same letters are not significantly different from each other according to Tukey's HSD, $\alpha = 0.05$.

locations. In Sidney, NE, in 2002 when temperatures were high and moisture extremely low, a very small percentage of the Burton and Baronesse tillers headed out and grain yields were negligible. Sidney, however, with the Otis background, headed relatively well. Grain yield of Burton was 8% that of Sidney. In Akron, CO, in 2004 when temperatures were cooler but moisture was limiting, Sidney again had significantly greater yield than Burton (39% greater than Burton). Harvest in 2004 at Stoneham and Ft. Collins, CO, was late due to cool temperatures and late rains in June and July. Under these conditions, abnormal for the high dry plains, Burton had higher grain yields than Sidney but not significantly so.

Sidney had greater grain yield, test weight, and percentage of plump kernels than Otis both when plots were artificially infested with RWA and when there were no or a light natural infestation of RWA. There was no negative agronomic affect from the transfer of RWA resistance into an Otis background. When RWAs were present, Sidney had a 39% yield advantage over its susceptible recurrent parent Otis. Under hot dry conditions typical of the high dry plains of eastern Colorado and western Nebraska, Sidney had an average of 60% greater grain yield than Burton. Sidney is the RWA-resistant cultivar better adapted to the high dry plains.

Availability

Seed of Sidney was deposited in the National Plant Germplasm System, where it will be available for research purposes, including development and commercialization of new materials. It is requested that appropriate recognition of the source be given when this cultivar contributes to research or development of new breeding lines or cultivars. Seed of Sidney will be distributed on request to breeders and geneticists in lots of 5 g. Requests for seed should be sent to the corresponding author. Parties interested in commercial production of Sidney can obtain seed from Colorado Agronomy Foundation Seeds, Dep. of Soil and Crop Sciences, Colorado State University, Ft. Collins, CO, 80523, or Nebraska Foundation Seed Division, 1071 County Road G, Room C, Ithaca, NE, 68033-2234.

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